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LOCALIZED PATTERNS IN PLANAR GAS-DISCHARGE SYSTEMS

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ABSTRACT

A summary is given of parts of the work that has been done on pattern formation in planar ac- and dc- gas-discharge systems with high ohmic and dielectric barrier respectively, at the Institute of Applied Physics of the University of Muenster. In addition, a qualitative reaction-diffusion model is reviewed that takes account of many of the effects that have been observed experimentally.

1. Introduction

Pattern formation in gas discharge systems is well-known since long time. It is astonishing that these phenomena have attracted so little attention in the field of "Nonlinear Dynamics and Pattern Formation" so far. It is the goal of the present review to report on the work that has been performed at the Institute of Applied Physics on localized patterns and that may serve to fill the gap in investigating gas discharge systems.

2. Experimental Set-Up and Results

The experimental investigations have been carried out with four different devices:

- A quasi-1-dimensional dc-system operated at room temperature where the edge of a thin metallic plate is opposite to the edge of a thin high-ohmic semiconductor wafer. The electrodes are separated by a discharge gap with discharge length ranging from some 100 μm to some mm. The pressure of the gas is about 10-100 hPa. The driving voltage is up to about 1 kV .[1]
- A quasi-2-dimensional dc-system operating at room temperature with a high-ohmic semiconductor layer with diameter in the range of some cm parallel to a glass plate coated with ITO and being transparent with respect to the radiation emitted from the discharge gap. Roughly the discharge length is 1 mm, the pressure 100 hPa, and the voltage up to 1 kV .[2]
- A quasi-2-dimensional dc-system similar to the former one. However, to increase the resistivity of the semiconductor the latter can be cooled down to about 90 K. In addition, the semiconductor resistivity can be controlled by an external IR-source. The discharge length ranges from about 100 μm to about 1 mm, the pressure is in the order of 100 hPa, and the voltage rises up to some kV .[3]
- A quasi-2-dimensional ac-system consisting of two parallel dielectric layers having a diameter in the order of several cm and a transparent ITO-contact at the outer sides. The dielectric plates are separated by a discharge space with a discharge length of approximately 1 mm. The pressure is in the order of some 100 hPa the amplitude of the driving voltage is up to some kV, and the period is in the range of 10^{-5} s.[4]

Among other things, self-organized patterns in the distribution of the discharge current do occur. These patterns can be observed optically due to the fact that excited states in the discharge gap emit light. Therefore, locally the current density distribution is reflected by the radiation density distribution which is approximately proportional to the current. All patterns listed below are recorded by optical means. Table 1 gives a listing of some of the observed patterns of the current distribution in the discharge space.

3. Qualitative Reaction-Diffusion Model for dc-Discharge and Theoretical Results

Most of the work has been performed using the three-component reaction diffusion systems similar to

$$\begin{aligned} u_t &= D_u \Delta u + f(u) - v - \kappa_3 w + \kappa_1 - \kappa_2 \int_\Omega u \, d\Omega, \\ \tau v_t &= D_v \Delta v + u - v, \\ \theta w_t &= D_w \Delta w + u - v, \end{aligned} \tag{1}$$

with

$$\begin{aligned} f(u) &= \lambda u - u^3, \\ & D_u, D_v, D_w, \tau, \theta, \lambda \geq 0, \\ & (u, v, w) = \left(u(x;t), v(x;t); w(x;t)\right), \\ & x \in \Re^1, \Re^2, \Re^3. \end{aligned}$$

The system of equations has been treated analytically and numerically with Neumann and periodic boundary conditions or with no boundary restrictions on infinite domain. The equation can be derived from an equivalent circuit for a layer system that consists of two high ohmic electrodes with linear behaviour having laterally homogeneous extension and being separated by a homogeneous material with S-shaped current-voltage characteristic. The high ohmic layer may represent high ohmic semiconductor electrodes or regions of anode and cathode fall. The material with S-shaped characteristic is a gas in our case. Dynamical behaviour is introduced to the system by considering a distributed capacity going along with the high ohmic layers and taking account of dielectric relaxation and a distributed inductivity describing charge carrier relaxation (Ref. 5-8, 12, 34, 39, 41-52). Table 1 contains also a review of some of the patterns resulting from analytical and numerical observations.

4. Acknowledgements

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Table 1

pattern	description	ref. experiment	ref. theory
stationary isolated filaments	- well localized solitary current density filaments - bifurcation cascades with increasing and decreasing number of filaments	dc-1-dim: 1,5-13 dc-2-dim: 2,14 ac-1-dim: 15 ac-2-dim: 9,16,17	1-dim: 1,6,7,8,10,11,12,39, 46,48 2-dim:47,49 3-dim:50, 48, 52
oscillatory tails of filaments	- basic feature to allow for molecules and various other composite structures at least for dc-systems	dc-2-dim: 2, 18	1-dim:40 2-dim:51
stationary filament clusters	- well defined filaments stick together to form „molecules“ - bifurcation cascades with increasing and decreasing number of filaments in „molecules“	dc-2-dim: 2,14,19 ac-2-dim: 4,16,17	2-dim:51
travelling isolated filaments	- single filament motion - bifurcation cascades with increasing and decreasing number of travelling filaments - filament interaction: scattering, generation, annihilation - spontaneous generation - generation due to splitting - coexistence of moving and travelling filaments	dc-1-dim: 9,11- 13,20,21, dc-2-dim: 22,23 ac-1-dim: 9,11 ac-2-dim: 4,15,17,24	1-dim:5,10,11,12,21 2-dim:47, 48, 50 3-dim:49, 50
travelling isolated filament clusters	- moving „molecules“	ac-2-dim: 4,16,25	1-dim: 2-dim:48

Table 1 Continuation

pattern	description	ref. experiment	ref. theory
oscillating filaments	- periodic filament due to splitting with consecutive fading of the new filament - filaments at fixed positions are switched on and off in succession, periodic process, only one filament on at given time - periodically breathing filaments with intermediate dumb-bell shape - circular shape with varying diameter - rotating „molecules“	dc-1-dim: 9,11,20 dc-2-dim: 2,26,27 ac-2-dim: 28	1-dim:10,11,46 2-dim:49
homogeneous dense filament structures	- stationary periodic filament pattern in 1-dim - stationary hexagonal filament pattern („crystals“) - drifting hexagonal filament pattern - „liquid“ state of filaments - „gaseous“ state of filaments - „gaseous“ state of molecules - rotating rings of filaments	dc-1-dim: 7,10,29 dc-2-dim: 14,22,30 ac-2-dim: 4,9,11,17,24,31	1-dim:10 2-dim:47, 52 3-dim:52
inhomogeneous dense filament structures	- coexistence of gaseous state and „crystalline“ or „liquid“ filament state, respectively - coexistence of stationary filaments and filaments travelling on closed loops - domains of dense filament patterns surrounded by homogeneous discharge regions - grain boundaries	dc-2-dim: 32 ac-2-dim: 4,17,24	

Table 1: Filamentary patterns observed in 1-and 2-dimensional dc- and ac-gas-discharge systems and theoretical treatment of equation (1)

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